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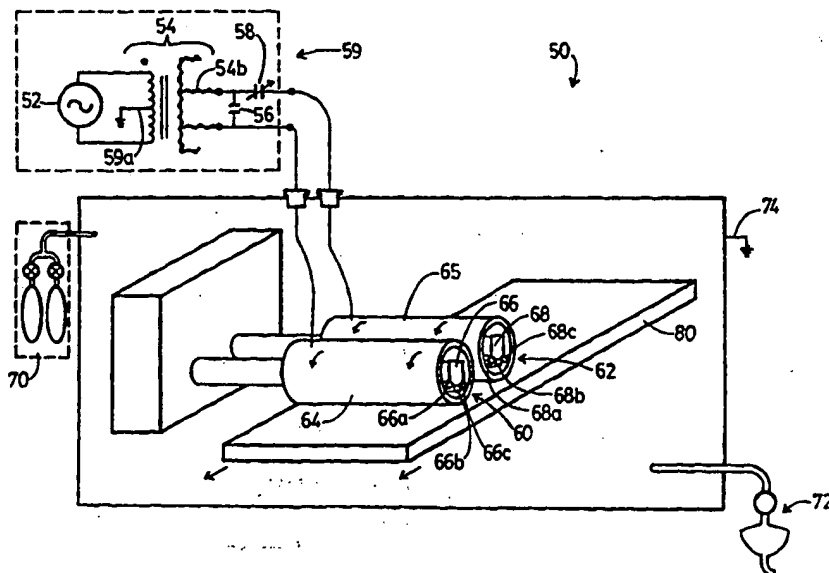
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## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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(21) International Application Number: PCT/US96/05588 (22) International Filing Date: 23 April 1996 (23.04.96) (30) Priority Data: 08/428,896                  25 April 1995 (25.04.95)                  US (71) Applicant: THE BOC GROUP, INC. [US/US]; 575 Mountain Avenue, Murray Hill, New Providence, NJ 07974 (US). (72) Inventors: LEHAN, John; 927 Palace Court, Benicia, CA 94510 (US). BYORUM, Henry; 910 Barstow Court, Sunnyvale, CA 94086 (US). HILL, Russel, J.; 8502 Buckingham Drive, El Cerrito, CA 94530 (US). ROUGH, J., Kirkwood; 264 South 4th Street, San Jose, CA 95112 (US). (74) Agents: PARSONS, Gerald, P. et al.; Majestic, Parsons, Siebert & Hsue, Suite 1450, Four Embarcadero Center, San Francisco, CA 94111-4121 (US).		(81) Designated States: CA, CZ, HU, JP, KR, SG, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).  <b>Published</b> <i>With international search report.          Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>

(54) Title: SPUTTERING SYSTEM USING CYLINDRICAL ROTATING MAGNETRON ELECTRICALLY POWERED USING ALTERNATING CURRENT



## (57) Abstract

A sputtering system (50) using an AC power supply (59) in the range of 10 kHz to 100 kHz uses two rotatable cylindrical magnetrons (60, 62). The rotatable cylindrical magnetrons (60, 62), when used for depositing a dielectric layer onto a substrate (80), clean off dielectric material that is deposited onto the target (64, 65). This prevents a dielectric layer on the target (64, 65) from acting like a capacitor and may help avoid arcing. Additionally, an impedance-limiting capacitor (58) can be placed in series in the electrical path between the targets (64, 65) through the transformer (54) so as to reduce arcing. This impedance-limiting capacitor (58) has a value much larger than the capacitor used to couple the power supply (59) to a target (64, 65) in radio frequency sputtering systems.

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**SPUTTERING SYSTEM USING CYLINDRICAL ROTATING  
MAGNETRON ELECTRICALLY POWERED USING  
ALTERNATING CURRENT**

5

**Background of the Invention**

The present invention relates to a sputtering system used to form thin film layers on glass. In particular, the system relates to a sputtering system which is used to produce electrically insulative dielectric layers.

Sputtering systems with alternating current (AC) power sources often are used to form electrically insulative dielectric layers on a substrate. One such system is disclosed in Szczyrkowski, et al. U.S. Patent No. 5,082,546. Figure 1 is a diagram of the AC-powered sputtering system 2 of Szczyrkowski, et al. This sputtering system 2 uses an AC power supply 4 connected by transformer 6 to targets 8, 8a, 8b and 8c. The system uses magnets 10, 10a, 10b, 10c, 10d and 10e to confine the plasma formed in the sputtering chamber 2.

Note that an additional direct current (DC) power supply 12 is used to maintain the anode 14 at a voltage above system ground 15. The additional DC power supply 12 is used in an attempt to avoid arcing in the sputtering system. The required DC power supply is expensive and may complicate the sputtering system design.

Additionally, the use of the anode 14 has a disadvantage in that the anode may become partially coated with the dielectric materials sputtered by the system

despite the use of baffles 18. Since the electrons in the plasma will not be as strongly attracted to the coated portions of the anode 14, the ions of the plasma will generally avoid that area as well due to the requirement of quasi-neutrality in the plasma. The scarcity of ions around the coated portions may produce an uneven deposition of the dielectric material onto the substrate 16.

Figure 2 is a cross-sectional view of two targets 20 and 22 used in a background art AC power supply sputtering system. During the operation of the sputtering system shown in Figure 2, magnets (not shown) partially contain the plasma in the magnetic fields 24 and 28 such that racetrack-shaped erosion zones 32 and 36 are formed. The erosion of the target material 20 and 22 results from ions in the plasma hitting the target and causing atoms from the target to sputter off. The re-deposition of the sputtered dielectric material on the targets 20 and 22 forms layers 40 and 42. These layers cover most of the sections of the targets 20 and 22, except for the racetrack-shaped erosion areas 32 and 36. When the targets 20 and 22 are connected to an AC power supply, the targets alternately act as the cathode and the anode. When an electrode such as target 20 acts as the anode, it attracts electrons in the plasma. In this situation, the magnetic fields 24 and 28 may impede the flow of electrons reaching the erosion areas, resulting in a high plasma impedance. The dielectric layer will prevent electrons from passing through to the target, and charge will be stored on the dielectric film 40. In this manner, the dielectric film 40 acts as a capacitive element. Although the switching between the positive and negative portions of the AC power supply can help to discharge the stored charge in this background art system, the system still may arc. Addi-

tionally, the capacitance caused by the dielectric film  
40 may be undesirable as it changes in time.

It is an object of the present invention to produce  
an improved sputtering system that uses AC power which  
5 avoids the problems of the prior art.

#### Summary of the Invention

An advantage of the present improved sputtering  
system involves the use of a rotatable cylindrical mag-  
netron with an AC power supply. The rotatable cylin-  
10 drical magnetrons use cylindrical rotating targets.  
When the target acts as the cathode, the deposited  
dielectric material is cleaned off of a portion of the  
target in the erosion zone. As the target rotates, dif-  
ferent areas of the target serve as the erosion zone so  
15 the whole target is cleaned. The cleaned portions of  
the target provide a path for the electrons to enter the  
target when the target acts as the anode. Since the  
dielectric material is cleared from the cylindrical  
magnetron, the target will not act as a capacitor and  
20 store charge, but will act as a resistive element. The  
use of rotatable cylindrical targets in the cylindrical  
magnetron helps avoid arcing, because charge is not  
stored on deposited dielectric layers of the target.

Additionally, a benefit of the present invention is  
25 the use of an impedance-limiting capacitor. This imped-  
ance-limiting capacitor is preferably used along with  
the AC power supply with frequencies in the 10kHz -  
100kHz range. This 10kHz - 100kHz range is lower than  
the frequency range used with radio frequency sputtering  
30 systems which have a capacitor to impedance match the  
system. The impedance-limiting capacitor is preferably  
placed in a secondary conductive path of the trans-  
former. The impedance-limiting capacitor helps prevent  
arcing in the system. The impedance-limiting capacitor

should have a relatively large capacitance value. The capacitance is preferably in the range of 0.2 to 10 $\mu$ F. The capacitance values in this range are much larger than the values of capacitors used to couple the electrodes with the higher frequency (megahertz to tens of megahertz) power supplies in RF sputtering systems. The capacitors used in radio frequency systems are typically about 10 to 100 picofarads.

The AC power supply has a frequency range which is high enough to avoid extinguishing the plasma between the reversal of the positive and negative portions of the signal, and is low enough so that the ions can follow the instantaneous electric field. A signal of 10kHz or greater is sufficient such that the recombination time of the plasma is greater than the time between the positive and the negative portions of the power supply, so that the plasma does not extinguish. The recombination time is typically determined by the distances between the targets and walls in the chamber.

An additional advantage of the present invention is that no extra DC voltage supply is required. The DC voltage supplies used in other sputtering systems complicate the design of the sputtering system and are expensive. The present invention also does not use an electrically permanent anode in the design. Permanent anodes in sputtering systems can get coated with dielectric material and cause the deposition profile onto the substrate to be distorted.

### Brief Description of the Drawings

The above and other features and aspects of the present invention will become more apparent upon reading the following detailed description in conjunction with the accompanying drawings, in which:

Figure 1 is a schematic diagram of a background art sputtering system using an AC power supply;

Figure 2 is a cross-sectional view of two targets used in a background art sputtering system with an AC power supply;

Figure 3 is a schematic diagram of the sputtering system of the present invention;

Figure 4 is a cross-sectional view of the cylindrical magnetrons used with the invention shown in Figure 3;

Figure 5 is a schematic diagram of an alternate embodiment of the present invention; and

Figure 6 is a schematic diagram showing an impedance-limiting capacitor positioned in the secondary winding of the transformer.

#### Detailed Description of the Preferred Embodiment

Figure 3 is a schematic diagram of the sputtering system 50 using an AC power supply 52. For the reasons discussed above, the AC power supply 52 preferably produces a power signal with a frequency in the range of 10kHz to 100kHz. In a preferred embodiment, the frequency of the AC power switch 52 is about 50kHz. Note that the frequency of the power supply 52 is less than the radio frequency range, so that reflected power is not an important concern. The AC power supply 52 is available from Halmar Robicon, ENI, Princeton Applied Research, or Advanced Energy. The AC power supply 52 is connected to transformer 54. Transformer 54 has a bifilar-wound secondary 54b that prevents the secondary 54b from becoming an autotransformer. Transformer 54 may also have a grounded center tap 54a for safety. The secondary of transformer 54 preferably has multiple taps that provide the function of impedance matching for the system. Transformer 54 is connected to a shunt capaci-



tor 56. Shunt capacitor 56 helps start the plasma if it extinguishes and reduces high-frequency noise. A typical value for shunt capacitor 56 is about 0.3 microfarad.

5       The impedance-limiting capacitor 58 is preferably connected in series in the electrical path that goes between the two targets through the transformer. In a preferred embodiment shown in Figure 6, the impedance-limiting capacitor 58'' is positioned in the secondary  
10       winding of transformer 54''.

      Looking again at Figure 3, as discussed above, the capacitance of the impedance-limiting capacitor 58 prevents arcing in the sputtering system. The impedance-limiting capacitor 58 limits the amount of  
15       current that can flow between the targets in case of a short. Impedance-limiting capacitor 58 is preferably a large, variable capacitor. Capacitance values for the impedance-limiting capacitor should be in the range of about 0.2 to 10 $\mu$ F. Since the frequencies of the AC  
20       power supply 52 are significantly lower than the radio frequency power supplies, reflected power is not a problem, and therefore the capacitance 58 is not required to avoid reflected power. The function of impedance matching is accomplished with the multiple taps on the  
25       secondary of the transformer as discussed above.

      The AC power from the circuitry 59 is connected to the cylindrical magnetrons 60 and 62. Cylindrical magnetrons are described in Wolfe et al. U.S. Patent No. 5,047,137 and McKelvey U.S. Patent No. 4,356,073, both  
30       of which are incorporated herein by reference. The cylindrical magnetrons are available from The BOC Group, Inc., Airco Coating Technology Division, located in Concord, California under the name C-MAG™. The rotatable cylindrical magnetrons 60 and 62 use rotatable  
35       cylindrical tubular targets 64 and 65. The cylindrical

rotatable tubular targets 64 and 65 preferably comprise an outer layer with a coat of a metallic or semiconductor material. The semiconductor material layer is preferably doped so that the layer is more conductive.

5 Silicon is commonly used as the sputtered material in cylindrical magnetron systems. The silicon can be reactively sputtered to produce silicon dioxide or silicon nitride layers on the substrate 80. Other typical dielectric materials used include  $TiO_2$ ,  $SnO_2$ ,  $Nb_2O_5$ , and

10  $Al_2O_3$ .

The rotatable cylindrical magnetron includes magnet assemblies 66 and 68. These magnet assemblies use magnets 66a, 66b and 66c as well as 68a, 68b and 68c. Since the magnet assemblies have three poles, they

15 produce two parallel containment areas. These containment areas form erosion zones when the target is acting as the cathode.

The action of the targets 60 and 62 can be better shown with respect to Figure 4. Figure 4 shows a cross-sectional view of two cylindrical magnetrons 60' and 62'.

20 Cylindrical rotatable tubular targets 64' and 65' are connected to the AC power supply shown in Figure 3, so that the targets 64' and 65' alternate between being the cathode (negative polarity) and anode (positive

25 polarity) of the system.

The magnet assembly 66 produces magnetic fields 90 and 92. The magnetic fields 90 and 92 contain the electrons in the plasma when the magnetron 60' is acting as the cathode so that the ions formed by the collisions

30 with the trapped electrons sputter off the target material 64' in the erosion areas 94 and 96. In reactive sputtering, the reactive ions combine with the sputtering material either at the target, the substrate or in the chamber atmosphere. The ions also remove the

35 dielectric material that has been redeposited onto the

surface of the cylindrical tubular target 64' outside the two erosion zones 94, 96. When the polarity of the power signal to the target 64' is reversed, the target acts as an anode and attracts electrons. Because of the rotation of the cylindrical tubular targets 64' and 65', the portions of the targets 64' and 65' which were eroded by the ions when the target acts as the cathode are rotated into different positions away from the magnetic fields, such as magnetic fields 94 and 96. As the cylindrical tubular target rotates, these cleaned areas allow for the electrons to make electrical contact with areas of the target away from the magnetic field. Additionally, since the targets 64' and 65' are cylindrical, there is more area available for the electrons to contact the targets 64' or 65' than in planar magnetron systems. This lowers the system impedance.

In the system of the present invention, the targets 64' or 65' do not store charge since the dielectric material has been eroded away. For this reason, there is not as large a capacitance when the system is operating. Additionally, since charge is not stored onto a dielectric material layer, the system of the present invention is not likely to arc as a result of the dielectric breakdown. This present sputtering system is different from the prior art AC sputtering systems shown with respect to Figure 2, since the dielectric layer 40 or 42 is deposited on top of target material and acts as a capacitive element in this prior art system.

Looking again at Figure 4, in the preferred embodiment, the distance between the cylindrical targets 98 is about 1-3 inches, and the distance between the cylindrical targets in the wall 99a and 99b is about four or more inches. These distances will ensure that the recombination time for the plasma is shorter than the time between positive and negative portions of the power

supply for a 10KHz minimum frequency signal. The arrangement of cylindrical magnetrons makes the plasma relatively unaffected by the arrangement of the chamber walls, since the discharge is maintained between the targets.

Looking again at Figure 3, a gas supply 70 and pump 72 are used to supply the gases at the required pressures for the sputtering deposition. Typical gases include oxygen, nitrogen, and noble gases. Typical gas pressures are 1-5 mTorr. The cathodes and power supply are electrically isolated from the chamber. This may be done by grounding the chamber at location 74. The substrate 80 is coated by the sputtered dielectric material. This substrate 80 moves underneath the targets. The line speed of the substrate 80, among other factors, determines the deposition thickness of the dielectric layer onto the substrate 80.

Figure 5 is a schematic diagram of an alternate embodiment of the present invention. In this alternate embodiment, only a single cylindrical magnetron 100 is used. The other cylindrical magnetron is replaced by an electrically conductive element 102. This electrically conductive element is connected to the circuitry 59' to supply the AC power supply to the cylindrical magnetron and electrically conductive element. It is preferred that the surface area of the electrically conductive material 106 is equivalent to that of the cylindrically rotatable target 104 on the cylindrical magnetron 100, so that neither the cylindrically rotatable magnetron 100 nor the electrically conductive material 102 maintains a DC bias voltage.

Various details of the implementation and method are merely illustrative of the invention. It will be understood that various changes in such details may be

within the scope of the invention, which is to be limited only by the appended claims.

## WHAT IS CLAIMED IS:

1. A sputtering system for forming a dielectric layer on a substrate comprising:

5 an alternating current power supply having two poles, the alternating power supply adapted to produce a power signal with positive portions in which the first pole has a more positive voltage than the second pole and negative portions in which the first pole has a more negative voltage than the second pole;

10 a chamber;

a rotatable magnetron in said chamber, said rotatable magnetron including a cylindrical tubular target responsive to the power signal at the first pole of the alternating current power supply and a magnet assembly adapted to direct the plasma to form an erosion zone on the cylindrical tubular target, the erosion zone being the area sputtered off of when the negative portion of the power supply is supplied to the cylindrical tubular target, wherein the cylindrical tubular target is adapted to rotate such that the erosion zone is located at different parts of the cylindrical target as the cylindrical target rotates and so that the sputtering off of the target removes some dielectric material deposited onto the target to form a cleaned portion of the target and wherein the removal of the dielectric from the cleaned portion of the target in portions away from the erosion zone reduces the impedance of the target as seen by the electrodes in the plasma when the positive portion of the power supply is supplied to the cylindrical tubular target and thus may prevent arcing, and

15  
20  
25  
30

an electrically conductive member in the chamber responsive to the power signal at the second pole of the alternating current supply.

2. The system of claim 1, wherein the electrically conductive member has a similar surface area as the cylindrical tubular target.

3. The system of claim 1, wherein the electrically conductive member comprises a second cylindrical magnetron, said second cylindrical magnetron acting as an anode while the first cylindrical magnetron acts as a cathode and the second cylindrical magnetron acting as a cathode while the first cylindrical magnetron acts as an anode.

4. The system of claim 1, wherein the arrangement of cylindrical magnetron and the electrically conductive member makes plasma relatively unaffected by the arrangement of the chamber walls.

5. The system of claim 1, wherein the alternating current power supply produces a power signal with a high enough frequency such that the plasma does not extinguish between the positive and negative portions of the signal and the power signal has a low enough frequency so that the ions and electrons can both follow the instantaneous electric fields.

6. The system of claim 5, wherein the power supply signal supplied by the alternating current power supply is between 10kHz and 100kHz.

7. The system of claim 5, wherein the alternating current power supply is connected to the cylindrical tubular target and the electrically conductive member through a transformer and an impedance-limiting capacitor connected in series in the electrical path between

the target and the electrically conductive member through the transformer, the capacitance of the impedance-limiting capacitor being sufficiently large that the impedance-limiting capacitor prevents arcing  
10 between the target and the electrically conductive member.

8. The system of claim 1, wherein no direct current power supply is connected to an electrode of the system.

9. A sputtering system for forming a dielectric layer on a substrate comprising:

an alternating current power supply adapted to produce a power signal with a frequency of less than a  
5 megahertz;

a chamber;

a transformer having two output terminals and two input terminals, the two input terminals connected between the first and second pole;

10 a cylindrical tubular target with associated magnet assembly located in said chamber electrically connected by a first electrical path to the first output terminal of the transformer;

an electrically conductive member in the chamber  
15 electrically connected by a second electrical path to the second output terminal of the transformer; and

an impedance-limiting capacitor connected in series in the electrical path between the target and the electrically conductive member through the transformer,  
20 the capacitance of the impedance-limiting capacitor being sufficiently large that the impedance-limiting capacitor prevents arcing in the system.



10. The system of claim 9, wherein the electrically conductive member comprises a second rotatable cylindrical tubular target with a second magnet assembly.

11. The system of claim 9, further comprising a shunt capacitor electrically connected between first and second output terminals of the transformer.

12. The system of claim 9, wherein the electrically conductive member has a similar surface area as the target.

13. The system of claim 9, wherein the arrangement of the target and the electrically conductive member makes the plasma relatively unaffected by the arrangement of the chamber walls.

5 14. The system of claim 9, wherein the alternating current power supply produces a power signal that has a high enough frequency so that the plasma does not extinguish between the positive and negative portions of the signal and has a low enough frequency so that the ions and electrons can both follow the instantaneous electric fields.

15. The system of claim 14, wherein the alternating current power supply produces a power signal with a frequency of between 10kHz and 100kHz.

16. The system of claim 9, wherein the impedance-limiting capacitor is a variable capacitor.

17. The system of claim 9, wherein the impedance-limiting capacitor has a capacitance value in the range of 0.2 to 10 $\mu$ F.

18. The system of claim 9, wherein the impedance-limiting capacitor is positioned in a secondary conductive path of the transformer.

19. The system of claim 9, wherein the transformer has additional windings and output terminals to impedance match the system.

20. A method for sputtering a dielectric layer on a substrate comprising the steps of:

providing a cylindrical target in a chamber;

5 applying an alternating current signal to the cylindrical target, said signal having positive and negative portions;

10 producing a magnetic field to produce an erosion zone about the cylindrical target such that ions strike the erosion zone when a negative portion of the signal is applied to the cylindrical target;

depositing a dielectric layer on the substrate;

15 cleaning off portions of the target by rotating the cylindrical target so that portions of the cylindrical target away from the erosion zone defined by the magnetic field have deposited dielectric material removed by the bombarding ions of the erosion zone; and

attracting electrons in the plasma to the cleared-off portions away from the erosion zone when the positive portion of the signal is applied to the target.

21. The method of claim 20, further comprising providing an additional cylindrical target connected to receive an alternating electrical signal that is posi-

5      tive when the first alternating electrical field is  
negative and is negative when the first electrical field  
is positive.

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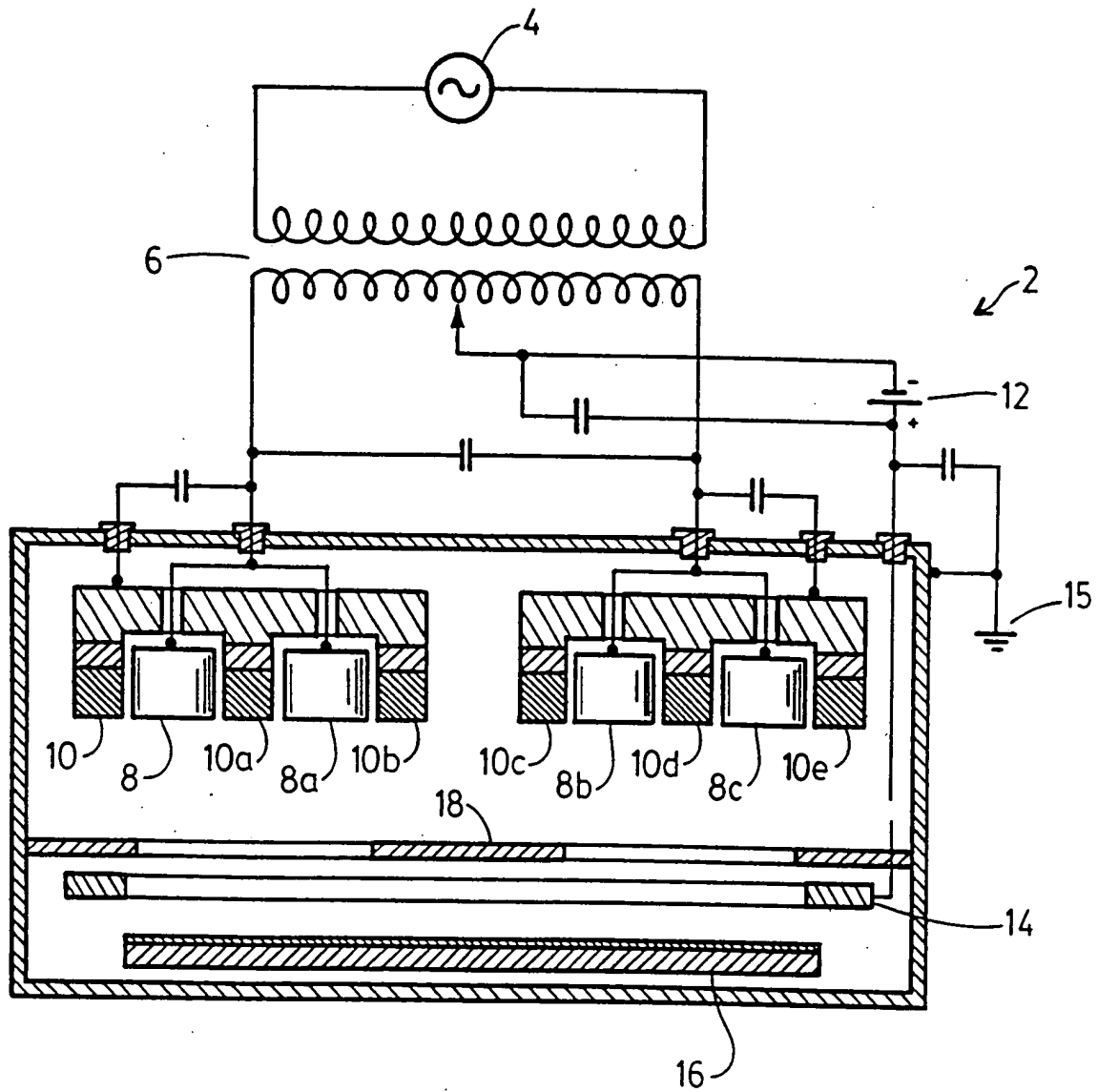


FIG. 1.  
( BACKGROUND ART )

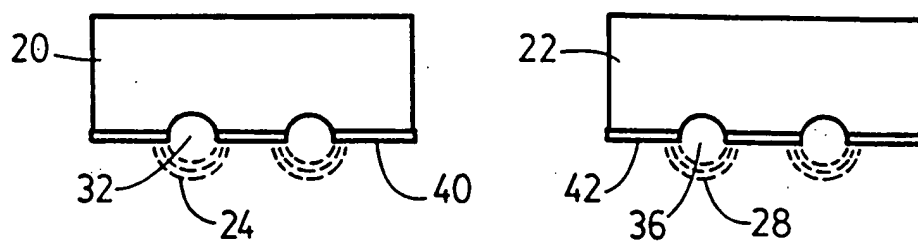


FIG. 2.

(BACKGROUND ART)

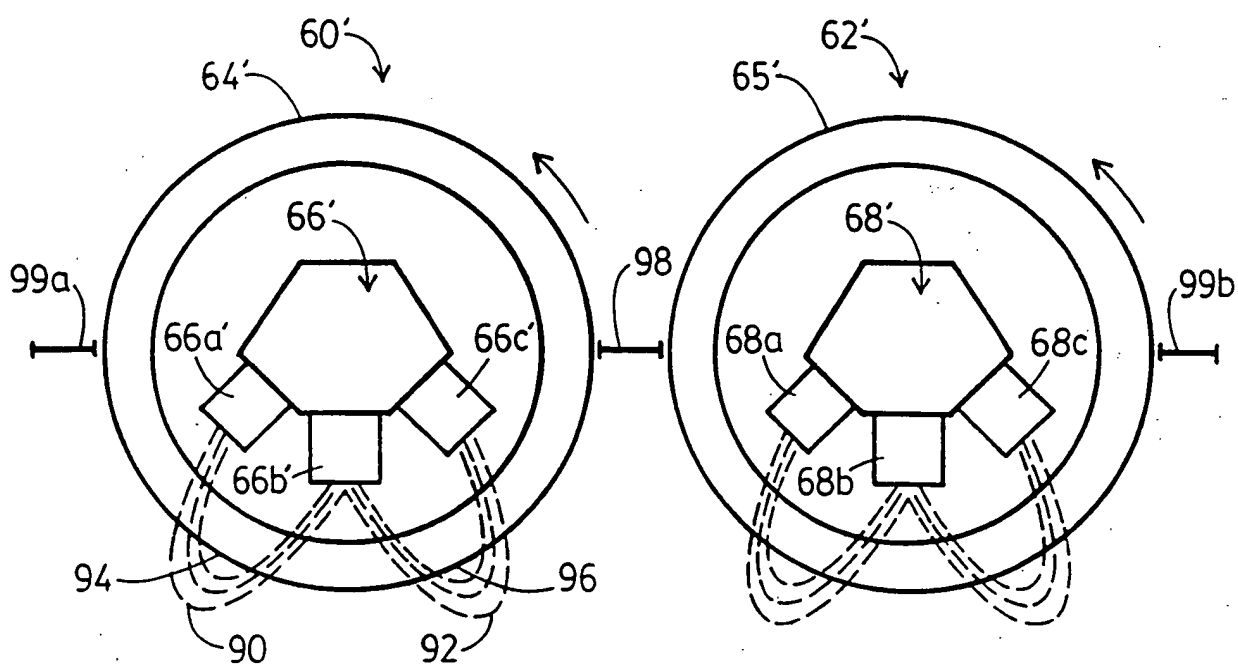


FIG. 4.

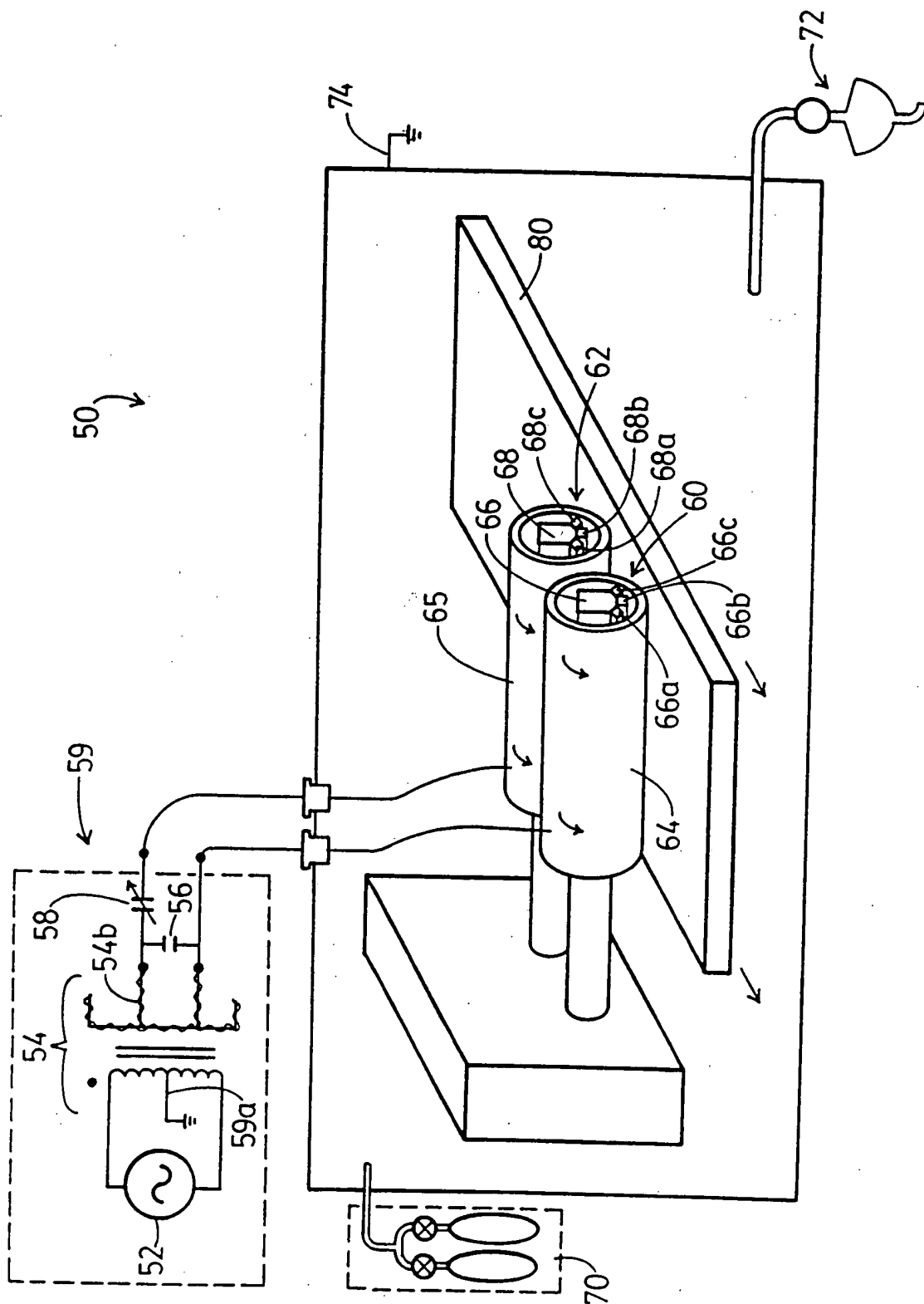


FIG. 3.

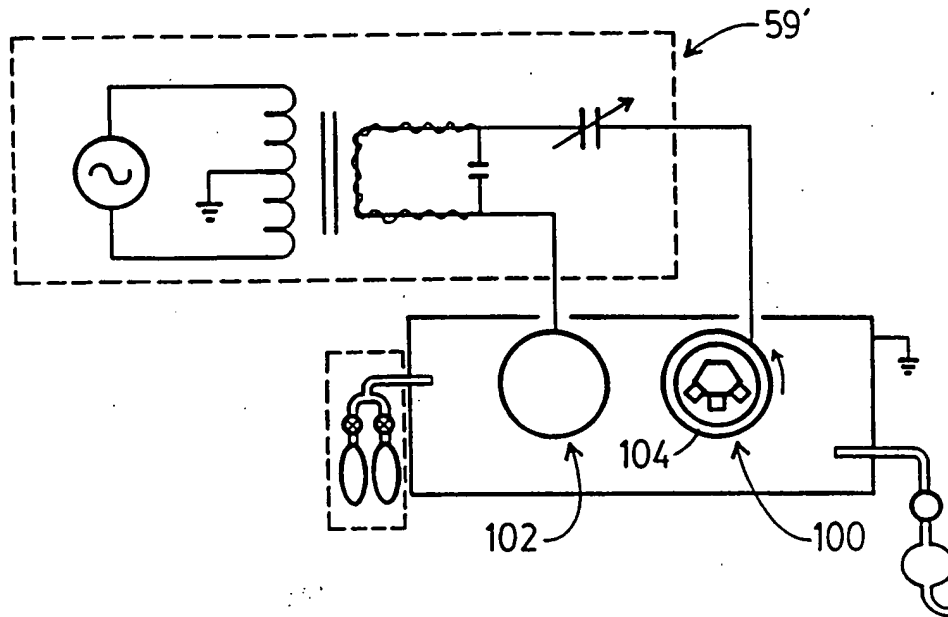


FIG. 5.

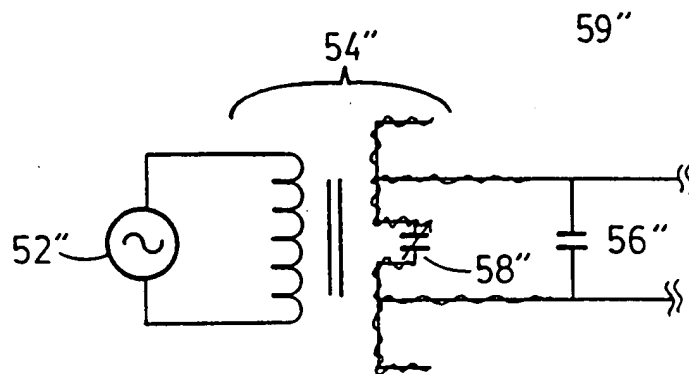


FIG. 6.

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US96/05588

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : C23C 14/34

US CL : 204/192.12, 298.08, 298.21, 298.22

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 204/192.12, 298.08, 298.21, 298.22

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A, 5,338,442 (BELKIND ET AL) 16 August 1994, see figure 1 and column 1.	1-6, 8 and 20-21
Y	US, A, 5,108,574 (KIRS ET AL) 28 April 1992, see figure 1 and column 1.	1-6, 8 and 20-21
Y	US, A, 5,082,546 (SZCZYRBOWSKI ET AL) 21 January 1992, see figure 1 and columns 1 and 2.	1-6, 8 and 20-21
Y	US, A, 5,399,252 (SCHERER ET AL) 21 March 1995, see figures 1-2, column 1, lines 6-35, and columns 3 and 4.	1-6, 8 and 20-21
Y	US, A, 3,767,551 (LANG, JR. ET AL) 23 October 1973, see figures 1-2.	7 and 9-19

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

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## INTERNATIONAL SEARCH REPORT

International application No.  
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## C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	US, A, 3,617,459 (LOGAN) 02 November 1971, see figure 5	7 and 9-19